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SPECTROSCOPIC DETECTION METHOD AND APPARATUS AND ULTRA-FINE PROCESSING METHOD AND APPARATUS USING SAME

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Abstract

Objective

The objective of this invention is to provide a spectroscopic detection method that can correctly detect the end point of milling or etching processing of a workpiece.

Constitution

Objective lens (11) and optical fiber (12) are set in a chamber; detection optical system (1) oriented to the surface of object (3) for detection is used to ensure that the light reflected from the surface of object (3) for detection and/or the light emitted from near its surface is received by incident end surface (120) of optical fiber (12); the spectrum of the received light is developed at the exit end of optical fiber (12), and its variation over time is detected so as to detect the end point of milling or etching processing of the workpiece.

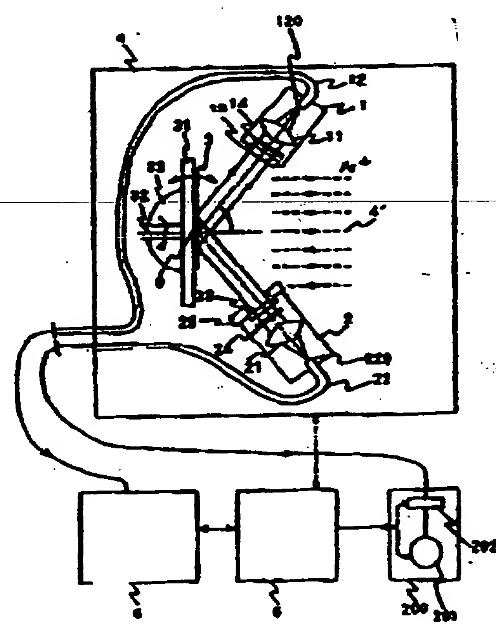

Figure 1

Claims

1. A spectroscopic detection method characterized by the following facts: a detection optical system composed of an objective lens and an optical fiber and oriented to the surface of the object for detection is used; light reflected from the surface of said object for detection and/or light emitted from near its surface is received by said optical fiber; the spectrum of the received light is developed at the exit end of said optical fiber; and variation in its intensity over time is detected.

2. The spectroscopic detection method described in Claim 1 characterized by the following facts: noise light to the optical fiber of said detection optical system is blocked with a black-body non-reflective surface, which has a spread corresponding to the directionality of said detection optical system; said non-reflective surface is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set crossing straight lines that form with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

3. The spectroscopic detection method described in Claim 1 characterized by the following facts: a beam of illuminating light with desired wavelength bandwidth and directionality is irradiated on the surface of said object for detection by means of an illuminating optical system; said illuminating optical system is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set on a straight line that forms with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

4. The spectroscopic detection method described in Claim 3 characterized by the fact that the angles of the optical axis of said detection optical system and the optical axis of said illuminating optical system with respect to said perpendicular line are set as the Brewster angle, and P-polarization light is detected as the reflected light.

5. The spectroscopic detection method described in Claim 3 characterized by the fact that the angles of the optical axis of said detection optical system and the optical axis of said illuminating optical system with respect to said perpendicular line are set as the Brewster angle, and P-polarization light or S-polarization light is detected selectively as the reflected light.

6. The spectroscopic detection method described in Claim 3 characterized by the fact that by turning said illuminating optical system ON/OFF, said reflected light and/or emitted light is selected and has its spectrum developed.

7. The spectroscopic detection method described in Claim 3 characterized by the fact that the spectral intensity distribution of said illuminating light is detected to correct the spectroscopic detection result of said reflected light.

8. The spectroscopic detection method described in Claim 7 characterized by the fact that the spectral intensity distribution of said illuminating light is detected with said detection optical system.

9. A spectroscopic detection apparatus characterized by the fact that it has the following parts: a detection optical system that is composed of an objective lens and an optical fiber and has directionality to the surface of the object for detection or to the vicinity of said surface, a spectroscopic means that receives the light reflected from the surface of said object for detection and/or the light emitted from near said surface by means of said optical fiber and develops the spectrum of the received light at the exit end of said optical fiber, and a detection means that detects variation of said spectral intensity over time.

10. The spectroscopic detection apparatus described in Claim 9 characterized by the following facts:

a black-body non-reflective surface having a spread corresponding to the directionality of said detection optical system is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set crossing straight lines that form with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

11. The spectroscopic detection apparatus described in Claim 9 characterized by the following facts:

it has an illuminating optical system that has a desired wavelength bandwidth and directionality and is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection; and it has an optical axis that forms with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

12. The spectroscopic detection apparatus described in Claim 11 characterized by the fact that

an aperture of field of view is set at a position conjugate to the surface of said object for detection in said illuminating optical system and/or said detection optical system.

13. The spectroscopic detection apparatus described in Claim 11 characterized by the fact that

it has a spectral intensity distribution detecting means that detects the spectral intensity distribution of the illuminating light from said illuminating optical system, and a correcting means that corrects the spectral intensity of said reflected light using said spectral intensity distribution.

14. The spectroscopic detection apparatus described in Claim 13 characterized by the fact that

said spectral intensity distribution detecting means is said detection optical system.

15. The spectroscopic detection apparatus described in Claim 11 characterized by the fact that

the angles of the optical axis of said detection optical system and the optical axis of said illuminating optical system formed with said perpendicular line are set as the Brewster angle, and it has a means for detecting P-polarization reflected light.

16. The spectroscopic detection apparatus described in Claim 11 characterized by the fact that

the angles of the optical axis of said detection optical system and the optical axis of said illuminating optical system formed with said perpendicular line are set as the Brewster angle, and it has a means for detecting P-polarization or S-polarization reflected light selectively.

17. The spectroscopic detection apparatus described in Claim 11 characterized by the fact that

it has a means for turning said illuminating optical system ON/OFF, and has a spectroscopic means which, by means of said light ON/OFF means, selects said reflected light and/or said emitted light and develops the spectrum.

18. An ultra-fine processing method characterized by the following facts: in this ultra-fine processing method, a laminated workpiece set in a vacuum chamber is processed by etching or milling, so that at least the uppermost layer of the workpiece is removed to a desired state; in this ultra-fine processing method,

a detection optical system, which is composed of an objective lens and an optical fiber set in said vacuum chamber and has a directionality to the surface of the workpiece or the vicinity of said surface, is used; the light reflected from the surface of the workpiece or the light emitted from the vicinity of said surface is received by said optical fiber; said received light is guided through said optical fiber out of said vacuum chamber; the received light is developed into its spectrum, and variation of the spectral intensity over time is detected, so that etching or milling is carried out to completion to realize the desired state.

19. The ultra-fine processing method described in Claim 18 characterized by the following facts:

noise light to the optical fiber of said detection optical system is blocked with a black-body non-reflective surface, which has a spread corresponding to the directionality of said detection optical system; said non-reflective surface is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set crossing straight lines that form with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

20. The ultra-fine processing method described in Claim 18 characterized by the following facts:

a beam of illuminating light with desired wavelength bandwidth and directionality is irradiated on the surface of said object for detection by means of an illuminating optical system; said illuminating optical system is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set on a straight line that forms with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

21. The ultra-fine processing method described in Claim 20 characterized by the fact that by turning said illuminating optical system ON/OFF, said reflected light and/or emitted light is selected and has its spectrum developed.

22. An ultra-fine processing apparatus characterized by the following facts: the ultra-fine processing apparatus has a means for etching or milling a workpiece having a laminated structure and set in a vacuum chamber, and it removes the uppermost layer of the workpiece to realize a desired state; in this ultra-fine processing apparatus,

there are the following parts: a detection optical system, which is composed of an objective lens and an optical fiber set in said vacuum chamber and has a directionality to the surface of the workpiece or the vicinity of said surface; a means in which the light reflected from the surface of the workpiece or the light emitted from the vicinity of said surface is received by said optical fiber, and said received light is guided through said optical fiber out of said vacuum chamber; a detection means that detects variation of the spectral intensity of the received light over time; and a means that performs etching or milling to completion of the desired state based on said variation of the spectral intensity over time.

23. The ultra-fine processing apparatus described in Claim 22 characterized by the following facts:

a black-body non-reflective surface having a spread corresponding to the directionality of said detection optical system is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing

through the cross point formed by said optical axis and the surface of said object for detection, and it is set crossing straight lines that form with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

24. The ultra-fine processing apparatus described in Claim 22 characterized by the following facts:

it has an illuminating optical system that has a desired wavelength bandwidth and directionality and is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection; and it has an optical axis that forms with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

25. The ultra-fine processing apparatus described in Claim 24 characterized by the fact that

it has a means for turning said illuminating optical system ON/OFF, and a means for selecting said reflected light and/or said emitted light.

26. The ultra-fine processing apparatus described in Claim 24 characterized by the following facts:

it has a means for preventing attachment of a coating film to the optical system due to etching or milling; this means has an opaque perforated filter having plural holes with aspect ratio [sic; large aspect ratio] set on the opposite side of said objective lens with respect to said optical fiber; and the central axes of said holes are nearly parallel to the orientation of said detection optical system.

27. The ultra-fine processing apparatus described in Claim 26 characterized by the following facts:

it has a means for preventing attachment of a coating film to the optical system due to etching or milling; this means has an opaque perforated filter having plural holes with aspect ratio [sic; large aspect ratio] set on the opposite side of said objective lens with respect to said optical fiber; and the central axes of said holes are nearly parallel to the orientation of said illuminating optical system.

Detailed explanation of the invention

[0001]

Technical field of the invention

This invention pertains to a spectroscopic detection method and apparatus for detecting the processing state of a thin film using spectroscopic means, as well as an apparatus that uses said spectroscopic detection method and apparatus to detect the end point of etching or milling.

In particular, this invention pertains to a spectroscopic detection method and apparatus for control of the processing state by etching or milling of a thin film of a semiconductor device, head of a magnetic disk memory, etc., as well as a method for detecting the end point of etching or ion milling using said method and apparatus.

[0002]

Prior art

In manufacturing of semiconductor devices and thin film magnetic heads, the following operation is usually carried out: the surface of the object made of a thin film and with a laminated structure is subject to etching or milling as chemical or physical processing so as to remove the uppermost layer film of the laminated structure to form the desired device. Said etching or milling operation is carried out using an apparatus having various structural members inside a vacuum chamber. Detection of the end portion of the etching or milling operation in the vacuum chamber, that is, detection of the point in time when the film for processing has been removed and the underlying film is exposed, is very important for guaranteeing correct cessation of the film processing and for ensuring the characteristics of the manufactured device.

[0003]

In prior art, for detecting the end point in film processing, test samples having the same film structure as that of the material of the product are prepared, and etched or milled. By changing the time, the actual time of the end point is detected, and the end point of etching or milling of the processing object product is controlled based on the detected time. Also, as another method that is different from the aforementioned method, light emitted from the workpiece during processing, that is, the light emission spectrum (the light emitted from the film under processing as the upper layer of the workpiece), is detected, and the end point is detected from a change in said light. As described in Japanese Kokai Patent Application Nos. Hei 6[1994]-318571 and Hei 6[1994]-318572, by means of a polychromator or another detector set outside the vacuum chamber, light emitted from the film under processing in the upper layer portion of the workpiece is focused, so that the light emission spectrum of this portion is detected.

[0004]

Problems to be solved by the invention

In the aforementioned conventional method for controlling the end point of etching or milling by means of the detection time, there are differences in film thickness between the test samples and the product samples, and there are differences in conditions of etching and milling,

so it is impossible to stop said etching or milling correctly at the end point, and it is impossible to form elements with excellent characteristics. Also, in the aforementioned method for detecting the end point by detecting the light emission spectrum from a film under processing, depending on the environment where the processing apparatus is set and other factors, said light emission spectrum may be buried in the ambient light, that is, the background noise light, so that it is hard to detect the end point with sufficient correctness. In particular, in the case of film processing with an ion milling apparatus, the light emitted by the neutralizer in the ion milling apparatus is a major background noise, so that it becomes almost impossible to detect the light emitted from the film under processing. The objective of this invention is to provide a spectroscopic detection method and apparatus, which can correctly control the end point of etching or milling without regard to the film thickness of the product sample, the etching/milling conditions, and the environment of the processing apparatus.

[0005]

Means to solve the problems

In the constitution of the spectroscopic detection method and apparatus of this invention, an optical system composed of an objective lens and an optical fiber is used as a detection optical system having a high detection directionality towards the surface of the object for detection or the vicinity of said surface. It is used to receive the light from the surface of the object for detection or from the vicinity of the surface at the incident end of the optical fiber. The light received in this way passes through said optical fiber and exits from the exit end of the optical fiber. The light is developed to get its spectrum, and variation in spectral intensity is detected.

[0006]

Also, in this case, a black-body non-reflective surface having a spread corresponding to the directionality of said detection optical system is set on the plane that contains the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set crossing straight lines that form with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line.

[0007]

However, in light emission analysis, light emission is weak and cannot be detected at a sufficiently high precision. Consequently, a beam of illuminating light with desired wavelength bandwidth and directionality is irradiated on the surface of said object for detection by means of an illuminating optical system; said illuminating optical system is set on the plane that contains

the optical axis of said detection optical system and the perpendicular line on the surface of said object for detection passing through the cross point formed by said optical axis and the surface of said object for detection, and it is set on a straight line that forms with said perpendicular line an angle equal to the angle between said optical axis and said perpendicular line. The reflected light that propagates on the detection optical axis from the surface of the object for detection is detected by the detection optical system, and its spectrum is detected. In this case, the spectral intensity distribution of the illuminating light is measured, and the spectral intensity distribution of the illuminating light is used to correct the results of detection of the reflected light spectrum.

[0008]

The spectral intensity distribution of the illuminating light for correction is detected by the detection optical system. The angles of said detection optical axis and illuminating optical axis formed with the perpendicular line are set as the Brewster angle, and P-polarization light is taken as the detection light. In addition, it is also possible to have the angles of said detection optical axis and illuminating optical axis formed with the perpendicular line set as the Brewster angle, and to have P-polarization or S-polarization light selectively detected. By turning said illuminating light source ON/OFF, said reflected light and/or said light emitted from the object for detection is selected and has its spectrum developed.

[0009]

When said spectroscopic detection method and apparatus of this invention are adopted in an etching or milling apparatus, in said etching or milling apparatus, a coating film is attached on said optical system accompanying the etching or milling operation. In consideration of this problem, the apparatus has an opaque perforated filter having plural holes with a large aspect ratio set on the opposite side of said objective lens with respect to said optical fiber; and the central axes of said holes are nearly parallel to the orientation of said detection optical system. Also, in the case of a reflected light spectrum, said opaque perforated filter is set with respect to said illuminating optical system.

[0010]

In the following, functions of the constitution of this invention will be explained. An objective lens and an optical fiber are set with the optical axis of said objective lens oriented in a desired direction to enable detection with high directionality of the surface of the object for detection or workpiece or vicinity of said surface, and, at the same time, the incident end of an optical fiber made of a relatively small optical fiber bundle diameter is set on the optical axis of the objective lens, so the light reflected from the surface of the workpiece or the light emitted

from the vicinity of the surface is detected at high directionality. As a result, incidence of a light noise component to the optical fiber is stopped, and it is possible to detect the state of the surface of the object for detection or workpiece at a high signal-to-noise ratio.

[0011]

Also, in this case, a black-body non-reflective surface having dimensions corresponding to the directionality of said detection optical system is set on the plane that contains the direction of the detecting system with a high directionality, that is, the optical axis of said detection optical system, and a perpendicular line on the surface of said object for detection, and it is set on straight lines that form with said perpendicular line an angle equal to the angle between said detection optical axis and said perpendicular line, that is, in a direction opposite the detection direction of the object for detection or workpiece, at each site where the black-body non-reflective surface crosses said straight lines. In this way, incidence of the light as a noise component into the optical fiber is stopped, so that it is possible to detect the state of the surface of the object for detection or workpiece at a high signal-to-noise ratio.

[0012]

Also, in light emission analysis, the intensity of the light emitted in etching or milling depends significantly on the type of workpiece, and there is a significant variation in the wavelength and intensity of the light emission spectrum, so that detection may be difficult. Even in this case, by illuminating with said high-directionality illuminating light in said detection direction, and detecting the reflected spectrum, it is possible to prevent light as a noise component in the vacuum chamber from being incident to the optical fiber of the light detection optical system, so that the surface state of the workpiece can be detected correctly, and it is possible to perform etching or milling correctly. In this case, by measuring the spectrum distribution of the illuminating light beforehand and using the determined value to correct the spectral result of the workpiece, it is possible to detect the reflected spectrum correctly.

[0013]

In addition, during etching or milling, a photoresist pattern is formed on the surface with respect to the detected light of the reflected spectrum, and the portion free of said photoresist pattern is to be detected. In this case, the light irradiated on the transparent photoresist portion undergoes multiple reflection inside the photoresist film, so that interference takes place, and even a small change in the film thickness of the photoresist leads to a significant change in the reflected spectral characteristics, making correct detection impossible.

[0014]

In consideration of this problem, the incident angle of the illuminating light is set as the Brewster angle, and P-polarization light is adopted for the illuminating light or detection light. Said illuminating light is not reflected from the surface of the photoresist, and correct detection is thus possible without regard to the thickness of the photoresist film.

[0015]

Also, depending on the film state of the object for detection or workpiece, S-polarization light may be required for high-precision detection. For such object, one may select from P-polarization and S-polarization. Depending on the film state of the object for detection or workpiece, the light emission analysis method may offer better detection precision in some cases, while the reflected spectroscopic method may offer better detection precision in other cases. Consequently, by turning the illuminating light source ON/OFF, one can select one of these two methods to ensure more precise detection for the specific sample as an object in any state.

[0016]

In an etching or milling apparatus, fine particles form in the milling fly and contaminate the detection optical system or illuminating optical system, so the optical systems are contaminated, and the detection precision decreases gradually. Consequently, an opaque perforated filter having plural holes with an aspect ratio corresponding to the directionality of the detection system is set in front of the objective lens or aperture window where said contamination of the optical system would take place. In this way, the etching gas or the fine particles formed in milling that were formerly the source of contamination can hardly reach said objective lens or window, since most of the particles collide with the hole [walls and are stopped]. As a result, contamination of the objective lens and window can be prevented.

[0017]

Embodiments of the invention

In the following, embodiments of this invention will be explained with reference to Figures 1-13.

Embodiment 1

Figure 1 is a schematic diagram illustrating a milling apparatus using a spectroscopic detection method as an embodiment of this invention. Figure 2 is schematic diagram illustrating the detection optical system of the milling apparatus shown in Figure 1. Figure 3 is a diagram

illustrating the black-body non-reflective surface of the illuminating optical system of the milling apparatus shown in Figure 1. Figure 4 is a diagram illustrating the perforated opaque filter in the detection optical system and illuminating optical system in the milling apparatus shown in Figure 1. Figure 5 is a graph illustrating variation in spectral reflective characteristics due to processing of the surface of a transparent film using the milling apparatus shown in Figure 1. Figure 6 is a graph illustrating variation in spectral reflective characteristics due to processing of a metal multi-layer film surface using the milling apparatus shown in Figure 1. Figure 7 is a diagram illustrating a spectral characteristics detection method of an illuminating light for correcting the spectral characteristics of a detection light. Figure 8 is a diagram illustrating correction of spectral characteristics using the spectral characteristics detection results from Figure 7. Figure 9 is a diagram illustrating another spectral characteristics detection method of an illuminating light for correcting the spectral characteristics of a detection light. Figure 10 is a diagram illustrating yet another spectral characteristics detection method of an illuminating light for correcting the spectral characteristics of a detection light. Figure 11 is a schematic diagram illustrating a dry etching apparatus using a spectroscopic detection method embodiment of this invention. Figure 12 is a diagram illustrating schematically a dry etching apparatus using another light emission spectroscopic detection method embodiment of this invention. Figure 13 is a graph illustrating spectral characteristics using the light emission spectroscopic detection method shown in Figure 12.

[0018]

In the following, this embodiment will be explained with respect to a milling apparatus using the spectroscopic detection method in this invention. In Figure 1, (1) represents a detection optical system; (2) represents an illuminating optical system; (3) represents a workpiece; (4) represents a vacuum chamber; (4') represents Ar ions; (45) [sic; (5)] represents a control system; (6) represents a spectroscope; (11) and (21) represent objective lenses of the detection optical system and illuminating optical system, respectively; (12) and (22) represent optical fibers of the detection optical system and illuminating optical system, respectively; (13) and (23) represent perforated opaque filters attached to the detection optical system and illuminating optical system, respectively; (25) represents a black-body non-reflective surface; (31) represents a rotating stage that holds and rotates workpiece (3); (32) represents the rotating shaft of rotating stage (31); (33) represents an elevating mechanism; (120) represents the incident end surface of optical fiber (12); (220) represents the irradiated end surface of optical fiber (22); (200) represents a power source housing; (201) represents a power source lamp; (202) represents a filter for selecting a desired wavelength of the light.

[0019]

As shown in Figure 1, (4) represents a chamber of the milling apparatus. The interior of this chamber is kept at a desired vacuum degree. Argon ions (4') generated from a generating source (not shown in the figure) fly with good directionality towards workpiece (3) kept on rotating stage (31) and they then collide against the workpiece. Said rotating stage (31) is rotated around rotating shaft (32) that is parallel to the paper surface, and it becomes elevating mechanism (33) around an axis that passes through center O of sample (3) and is perpendicular to the paper surface. In the ion milling operation, the elevating angle is determined corresponding to the milling characteristics of workpiece (3), the 3-dimensional shape of the resist that acts as a mask, and the desired 3-dimensional shape after processing. Then, as rotating stage (31) is rotated, milling is carried out.

[0020]

In the following, the principal constitution of detection optical system (1) will be explained with reference to Figure 2. Said detection optical system (1) is fixed on elevating mechanism (33) (the fixing mechanism is not shown), and it is attached appropriately so that its optical axis is approximately oriented towards the center of rotating stage (31). As shown in the figure, for detection optical system (1), objective lens (11) and perforated opaque filter (13) are accommodated in a basket, which is connected to optical fiber (12). Assuming that the focal distance of said objective lens (11) is f, for said f, incident end surface (120) of optical fiber (12) is nearly at the focal position f. Said optical fiber (12) is composed of a single fiber or plural fibers. Effective aperture diameter d of said incident end (120) is sufficiently smaller than focal distance f of objective lens (11).

[0021]

In the aforementioned constitution, light that is incident on objective lens (11) and is taken into optical fiber (12) is only light with a divergence in the range of the following $\Delta\theta$ with respect to the optical axis of detection optical system (1) as shown in the figure.

$$\Delta\theta \leq d/2f$$

For example, when f is 30 mm, and d is 1 mm, it is possible to detect only light with a divergent angle $\Delta\theta$ of about 1° or smaller.

[0022]

In the following, illuminating optical system (2) will be explained. Just like detection optical system (1), illuminating optical system (2) is fixed on elevating mechanism (33) (the fixing mechanism is not shown in the figure), and its optical axis is oriented approximately to the center of the rotating stage. The constitution of illuminating optical system (2) is almost identical to that of detection optical system (1). Objective lens (11) of detection optical system (1) corresponds to objective lens (21) of illuminating optical system (2), and perforated opaque filter (13) of detection optical system (1) corresponds to perforated opaque filter (23) of illuminating optical system (2). Said objective lens (21) and perforated opaque filter (23) are accommodated in a basket, which is connected to optical fiber (22). As shown in Figure 2, effective aperture diameter d' of illuminating end surface (220) of said optical fiber (22) and focal distance f' of objective lens (21) are almost equal to effective aperture diameter d of incident end surface (120) of optical fiber (12) of detecting optical system (1) and focal distance f of objective lens (11), respectively.

[0023]

A major difference of said illuminating optical system (2) from detection optical system (1) is that black-body non-reflective surface (25) is set in it as shown in Figure 1. As shown in the figure, said black-body non-reflective surface (25) is on the plane that contains the optical axis of said detection optical system (1) and the perpendicular line on the surface of said object (3) for detection and passing through the cross point formed by said optical axis and the surface of said object (3) for detection, and it is set crossing straight lines that form with the perpendicular line the same angle as angle θ formed between said optical axis and said perpendicular line. As shown in the figure, it is set at the exit end of illuminating optical system (2). It has a spread corresponding to the directionality of said detection optical system (1). The spread of said black-body non-reflective surface (25) has inner diameter d' that is a little larger than the diameter of the light at the exit end of illuminating optical system (2), and has outer diameter that is larger than $d' + 2L\Delta\theta$ with respect to optical pass length L from objective lens (21) of illuminating optical system (2) to objective lens (11) of detection optical system (1).

[0024]

In the following, surface (251) of black-body non-reflective surface (25) will be explained with reference to Figure 3. As shown in the figure, said surface (251) may be made of blades of cutter knives. Said blades cross each other at an acute angle to form sharp tips. Several layers of blades (251) of said cutter knives are laminated to form black-body non-reflective surface (25). When light is incident on said black-body non-reflective surface (25), no matter

what the incident direction is, almost all the light is reflected by plural rounds on blade surfaces (252) of cutter knives, and it then exits to the outside.

[0025]

The number of rounds of reflection depends on the acute angle of said blades (251) and the incident angle. For example, the constitution may be such that reflection takes place for 5 or more rounds on average. According to experiments, when reflection occurs for 5 or more rounds on average, if said reflectivity is 60% or lower, 10% or less of the incident light returns from the surface, so noise light can be reduced significantly. In addition, when the reflectivity is decreased, the amount of light returned from the surface, that is, the aforementioned noise light, can be further reduced.

[0026]

In the following, perforated opaque filter (13) of detection optical system (1) and perforated opaque filter (23) of illuminating optical system (2) will be explained with reference to Figure 4. As they have the same constitution, perforated opaque filter (23) of illuminating optical system (2) will be taken as an example for explanation. As shown in the figure, said perforated opaque filter (23) has holes (231) and opaque portions (232) set alternately on its cross-section. Said holes (231) have a circular shape. They have diameter D, hole pitch P and filter thickness t. In order to make effective use of the illuminating light, the ratio of diameter D to hole pitch P is selected to be as large as possible. Also, the relationship between hole pitch P and filter thickness t is optimized corresponding to the directionality of illuminating optical system (2). By means of said perforated opaque filters (13) and (23), it is possible for the optical systems to always be under the same conditions without contamination by attachment of milling particles on them.

[0027]

In the following, the overall constitution of the milling apparatus will be explained again with reference to Figure 1. Detection optical system (1) and illuminating optical system (2) are set inside chamber (4), and in order to feed in illuminating light and to guide out the detection light, optical fibers (22) and (12) that are extended out of chamber (4) are used, respectively. In light source housing (200) set outside chamber (4), lamp (201), such as a halogen lamp or a xenon lamp, and filter (202) for selecting a desired wavelength of light are set. The light exit from said light source lamp (201) passes through filter (202) to obtain the desired spectral distribution. Then, it is guided into optical fiber (22). It then goes through objective lens (21) and perforated opaque filter (23) and is irradiated on workpiece (3). The reflected light is then

received by detection optical system (1). The detection light received by detection optical system (1) inside chamber (4) goes through objective lens (21), perforated opaque filter (13) and objective lens (11), and then optical fiber (12) to spectroscope (6) set outside chamber (4) to determine the spectral distribution.

[0028]

Control system (5) performs control of the milling apparatus in chamber (4), control of light source housing (200), control of spectroscope (6), etc., and, at the same time, it controls the overall system. That is, elevating angle θ of sample table (31) is selected corresponding to the material and the pattern structure of workpiece (3), and it is adjusted to the desired angle by means of elevating mechanism (33). Corresponding to elevation of said adjusted elevating mechanism (33), detection optical system (1) and illuminating optical system (2) that are fixed on said elevating mechanism (33) are interlocked with each other. Although not shown in the figure, Ar ions (4') obtained from an Ar ion source not shown in the figure are irradiated on workpiece (3) to perform milling of the surface of the workpiece. In order to process workpiece (3) uniformly in said ion milling operation, sample table (31) is rotated during the processing. In this way, it is possible to perform the ion milling processing appropriately corresponding to the spectral distribution of the detection light.

[0029]

In the following, the aforementioned ion milling processing will be explained in detail. On the surface of said workpiece (3), a photoresist pattern having a shape corresponding to the processing pattern is formed with photoresist formed at prescribed sites and absent in remaining portions. As said Ar ions (4') perform milling processing for said photoresist, they also process the film in the portion without said resist. Immediately before the start of the milling operation, the illuminating light is irradiated on the surface under processing. At the same time that milling begins, reflected light is received by detection optical system (1), and the detected light is guided to spectroscope (6). The state of variation in the reflected spectral distribution over time in milling is detected intermittently with a certain sampling interval. In company with said milling, the reflected spectral characteristics of the surface under processing vary. Consequently, it is possible to detect the end point of milling by measuring said variation.

[0030]

In the following, the state of variation in the spectral reflection characteristics of a surface processed by milling will be explained with reference to Figures 5 and 6. Figure 5 is a diagram illustrating the spectral reflection characteristics when a transparent film is processed. Figure 6 is

a diagram illustrating the spectral reflection characteristics when a metal laminated film is processed. In the case of processing a transparent film as shown in Figure 5, corresponding to the film thickness, the period of multiple interference of the reflected spectrum varies as indicated by the solid line and broken line shown in the figure. Consequently, the film thickness is derived from the period, and the processing comes to an end when the multiple interference waveform displays a period corresponding to the desired film thickness. Also, in the case of processing a metal laminated film shown in Figure 6, the materials of different layers have different reflection spectral characteristics, so the spectral reflection characteristics vary from the solid line to the broken line as shown in the figure. By detecting such variation, it is possible to detect the end point of processing and to stop the processing.

[0031]

In the reflection spectroscopic detection method explained above, the workpiece is irradiated with an illuminating light. However, for a conventional illuminating light, the intensity varies for different wavelengths. Consequently, it is preferred that the spectral characteristics be corrected based on differences in wavelength intensity. In the following, a method for correcting will be explained with reference to Figures 7 and 8. Figure 7 is a diagram illustrating a method for detecting the spectral characteristics of an illuminating light for correcting the spectral characteristics of the detection light. Figure 8 is a diagram illustrating correction of the spectral characteristics using the results of the spectral characteristics detection of Figure 7. Although not shown in the figure, an automatic adjusting means is installed for adjusting the detection direction of detecting optical system (1) and the illuminating direction of illuminating optical system (2). By means of said automatic adjusting means, before or after processing of the object for detection, the positions of detection optical system (1') and illuminating optical system (2') are adjusted as indicated by the broken lines shown in Figure 7, so that the directions of light detection and illumination are changed, respectively. In this way, the illuminating light of illuminating optical system (2') is not irradiated on workpiece (3). Instead, it travels directly to detection optical system (1') and is detected. In this way, the illuminating light is directly detected, so that the spectral characteristics of the illuminating light are obtained.

[0032]

Figure 8(a) is a graph illustrating spectral characteristics $I_i(\lambda)$ in illuminating optical system (2') and detection optical system (1') shown by the broken lines in Figure 7. Figure 8(b) is a graph illustrating spectral characteristics $I_D(\lambda)$ of the surface under processing in the end point detecting state in illuminating optical system (2) and detection optical system (2) [sic; (1)]

indicated by the solid lines in Figure 7. From said spectral characteristics $I_i(\lambda)$ and $I_D(\lambda)$, one gets:

$$R(\lambda) = I_D(\lambda)/I_i(\lambda)$$

As shown in Figure 8(c), the true reflected spectral characteristics are obtained. Said $R(\lambda)$ can be obtained easily from the memory of control system (5) and its operation function.

[0033]

In the following, an example of modification of said correcting method will be explained. Figure 9 is a diagram illustrating another spectral characteristics detecting method of illuminating light for correcting the spectral characteristics of the detection light. In Figure 9, (210) represents a prism; (211) represents a spacer. Light exiting from illuminating optical system (1) is incident on prism (210), and is totally reflected from the bottom surface of the prism. Consequently, a reflectivity nearly 100% can be realized without regard to the wavelength of the incident light. More precisely, there is a certain difference in the reflective spectral characteristics between the incident surface and exit surface of prism (210). However, by using an anti-reflection coating, it is possible to suppress the error to 1% or lower. In addition, even when an anti-reflection coating is not applied, it is still possible for accurate correction because the reflective spectral characteristics at each wavelength are known. In this way, by deriving the spectral characteristics of the illuminating light, it is possible to accurately correct for reflective spectral characteristics just as in the method explained in Figure 7.

[0034]

In the following, another example of modification of said method for correction will be explained. Figure 10 is a diagram illustrating another spectral characteristics detecting method of illuminating light for correcting the spectral characteristics of the detection light. As shown in Figure 10, the optical fiber that guides the light exiting from light source lamp (201) to illuminating optical system (2) is branched, or another optical fiber (221) is used to guide the light to spectroscope (6). The incident light to prism (61) in spectroscope (6) is switched with shutter (62), and the spectral characteristics of light source lamp (201) are detected alternately with the spectral characteristics from reflected spectroscopic detection of workpiece (3) not shown in the figure. Just as in the embodiment explained with reference to Figures 7, 8 and 9, it is also possible to derive the reflected spectral characteristics correctly in this case.

[0035]

Embodiment 2

In the following, another embodiment of this invention will be explained. In said Embodiment 1, ion milling was performed. For a dry etching apparatus, the mechanism is the same, except that there is no elevating mechanism. Figure 11 is a schematic diagram illustrating a dry etching apparatus in a light emission spectroscopic detection method in an embodiment of this invention. As shown in the figure, a reactive ion beam is irradiated with good directionality on workpiece (3). In this case, the generated light is detected by detection optical system (1) with a relatively high directionality. For the detection direction of said detection optical system (1), black-body non-reflective surface (25') is set in the direction of normal reflection by workpiece (3). In this case, said normal reflection direction refers to the direction obtained by bisecting the angle formed by the detection direction in the plane that contains the detection direction and a normal erected on the surface of the workpiece. In this constitution, surrounding stray light other than the light emitted in company with dry etching is not picked up, so that light emission analysis can be carried out with a high SN ratio.

[0036]

In the following, an example of modification of this embodiment of this invention will be explained. Figure 12 is a schematic diagram illustrating a dry etching apparatus using a light emission spectroscopic detection method in another embodiment of this invention. Figure 13 is a graph illustrating spectral characteristics using the light emission spectroscopic detection method of Figure 12. In this embodiment, the light emission state of the region in the vicinity above the surface of the workpiece is detected. Black-body non-reflective surface (25') is set in the detection direction of the detection optical system. Just as in the embodiment shown in Figure 11, in this case, little surrounding noise is received in light emission spectroscopic detection.

[0037]

Figure 13 is a graph illustrating results obtained from light emission analysis using the aforementioned constitution. The abscissa represents wavelength, and the ordinate represents relative light emission intensity distribution. When the desired film for etching film is being processed, the spectral waveform indicated by the solid line in Figure 13 is obtained. After completion of processing of this film, the film below this film is exposed, and the spectral distribution indicated by the broken line appears. Consequently, the instant when the level of the spectrum indicated by the solid line decreases and the spectral waveform indicated by the broken line is detected, etching is stopped.

[0038]

Embodiment 3

In the following, yet another embodiment of this invention will be explained. In this embodiment, the end point of milling or etching is detected. In this embodiment, the constitution differs from that of Embodiment 1 shown in Figure 1 in that it has polarizers (14) and (24) set between objective lenses (11), (21) and perforated opaque filters (13), (23), respectively, for detecting the end point. In this embodiment, the spectral reflection characteristics of the processing layer and the lower layer of the surface of the workpiece are similar to each other, and it is hard to detect the end point. When the material of the films is known, one can predict such state of similarity. In this case, control system (5) turns the power source of light source lamp (201) OFF, or a shutter is set in light source housing (200) to block light from light source lamp (201). That is, light from illuminating optical system (2) is blocked, and milling is carried out. The light emitted in company with milling is detected with detection optical system (1), and light emission analysis is carried out with spectroscope (6).

[0039]

Usually, compared with reflected spectroscopy, the intensity of light obtained in light emission spectroscopy is lower. Consequently, in spectroscope (6), a photomultiplier or other high-sensitivity detector is used to detect light in a specifically defined spectral range. Switching of such detecting means is carried out with control system (5), which controls selection of spectroscope (6) and ON/OFF control of illuminating housing (200). When a workpiece is processed with a photoresist used as a mask and the proportion of the portions covered with said photoresist is very large, the optical signal obtained from the open portions not covered with the photoresist, that is, the reflected light in the case of reflection spectroscopy or the emitted light in the case of light emission is much weaker than the undesired light, that is, the noise light, from the covering photoresist.

[0040]

However, the film thickness of the photoresist also varies in company with milling or etching. Consequently, if there is a significant change in the spectral distribution of light from this portion due to said variation, the detected optical signal from the open portions would be buried in this variation of spectral distribution. In this case, P-polarization is realized for illuminating light used in reflected spectroscopic detection by means of polarizer (24) in illuminating optical system (2), or for detection light by means of polarizer (14) in the detection optical system, and the incident angle to workpiece (3) is set as the Brewster angle, so that there is no reflection from the photoresist surface, multiple interference is zero, and noise light is at an

invariant constant level independent of variation in the film thickness of the photoresist portion. As a result, variation in the spectral distribution of the detection light from the open portions can be detected correctly.

[0041]

When the workpiece has a transparent film structure, and the film is processed for a prescribed amount, it is preferred that multiple interference in company with the film structure be actively exploited. In consideration of this case, in this embodiment, the optical axes of the illuminating light and detection light are set as the Brewster angle, and polarizer (24) in the illuminating optical system or polarizer (14) in the detection optical system is set appropriately to enable rotation around the optical axis.

[0042]

In this constitution, when multiple interference is actively exploited to detect the end point, so-called S-polarization light is used for detection. On the other hand, when said multiple interference of the photoresist is a problem, so-called P-polarization light is used for detection. In this way, one can freely select said S-polarization or P-polarization for polarizer (24) in the illuminating optical system or polarizer (14) in the detection optical system. For example, a mechanism for rotary switching of said polarizer (24) and polarizer (14) (not shown in the figure) can be adopted to realize the aforementioned function easily. In the aforementioned embodiment, polarizers (14) and (24) are set in detection optical system (1) and illuminating optical system (2), respectively. However, it is also possible to set only one polarizer in either the detection optical system or the illuminating optical system.

[0043]

Also, in the aforementioned embodiments of this invention, reflected light or emitted light is incident into an optical fiber, and the reflected spectrum or light emission spectrum is detected. However, it is also possible to have both reflected light and the emitted light incident into an optical fiber, and both the reflected spectrum and emitted spectrum are detected. In this case, as shown in Figures 8 and 13, the reflected spectrum and the emitted spectrum have clearly different spectra waveforms, so that they can be distinguished from each other. Also, when the intensity of the emitted light is low while the intensity of the reflected light is high, in order to lower the intensity of the illuminating light so as to realize balance between the two intensities, for example, [light] with a prescribed wavelength is picked up and amplified with a photomultiplier. In this way, spectroscopic detection can be realized easily.

[0044]

Effect of the invention

As explained in detail above, according to the constitution of this invention, it is possible to provide a spectroscopic detection method and apparatus, which can detect correctly the surface state and variation in the surface state irrelevant to the film thickness of the workpiece or object for detection, the conditions of etching or milling, and the environment of the processing apparatus. In particular, it is possible to correctly detect the end point of processing of milling or etching of the film structure of a workpiece. Consequently, by controlling the end point, the processing yield is improved, and the processing precision is improved. Also, this invention provides an ultra-fine processing method and apparatus that uses said spectroscopic detection method and apparatus.

Brief description of the figures

Figure 1 is a schematic diagram illustrating a milling apparatus using a spectroscopic detection method embodiment of this invention.

Figure 2 is a schematic diagram illustrating the detection optical system of the milling apparatus shown in Figure 1.

Figure 3 is a diagram illustrating the black-body non-reflective surface of the illuminating optical system of the milling apparatus shown in Figure 1.

Figure 4 is a diagram illustrating the perforated opaque film in the detection optical system and illuminating optical system in the milling apparatus shown in Figure 1.

Figure 5 is a graph illustrating variation in spectral reflective characteristics due to processing of the surface of a transparent film using the milling apparatus shown in Figure 1.

Figure 6 is a graph illustrating variation in spectral reflective characteristics due to processing of a metal multi-layer film surface using the milling apparatus shown in Figure 1.

Figure 7 is a diagram illustrating a spectral characteristics detection method of illuminating light for correcting the spectral characteristics of the detection light.

Figure 8 is a diagram illustrating correction of spectral characteristics using spectral characteristics detection results from Figure 7.

Figure 9 is a diagram illustrating another spectral characteristics detection method of illuminating light for correcting the spectral characteristics of the detection light.

Figure 10 is a diagram illustrating yet another spectral characteristics detection method of illuminating light for correcting the spectral characteristics of the detection light.

Figure 11 is a schematic diagram illustrating a dry etching apparatus using a spectroscopic detection method embodiment of this invention.

Figure 12 is a diagram illustrating schematically a dry etching apparatus using a light emission spectroscopic detection method in another embodiment of this invention.

Figure 13 is a graph illustrating spectral characteristics using the light emission spectroscopic detection method shown in Figure 12.

Brief explanation of reference numbers

1	Detection optical system
2	Illuminating optical system
3	Workpiece
4	Vacuum chamber
5	Control system
6	Spectroscope
11, 21	Objective lens
12, 22	Optical fiber
13, 23	Perforated opaque filter
14, 24	Polarizer
25	Black-body non-reflective surface
31	Rotating stage for holding and rotating workpiece
32	Rotating shaft of rotating stage
33	Elevating mechanism
61	Prism
62	Shutter
120	Incident end surface of optical fiber
220	Illuminating end surface of optical fiber
200	Light source
201	Lamp
202	Filter
210	Prism
211	Spacer
221	Branched or separate optical fiber
231	Circular hole
232	Opaque portion
251	Blade of cutter knife
252	Surface of blade of cutter knife

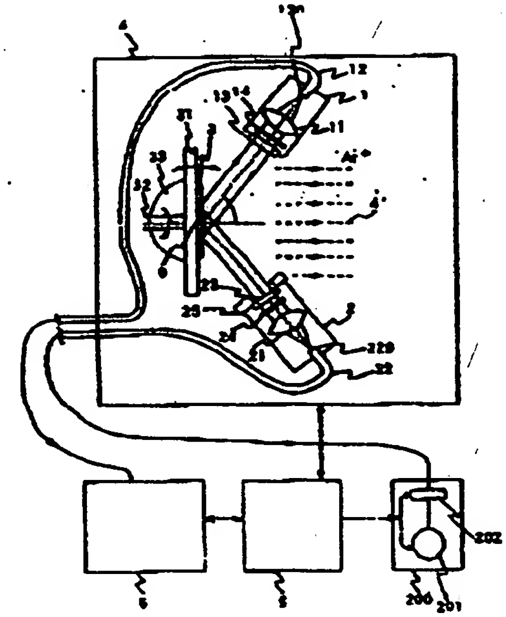

Figure 1

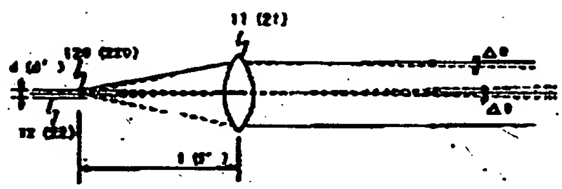

Figure 2

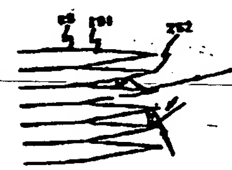

Figure 3

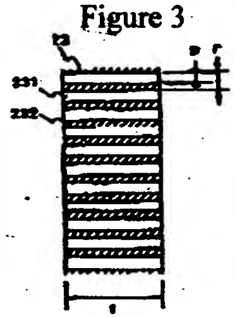

Figure 4

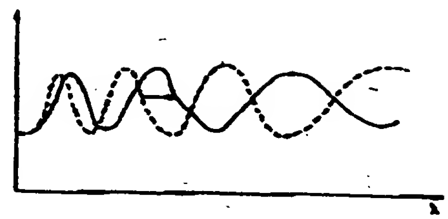

Figure 5

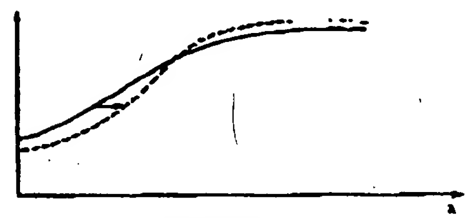

Figure 6

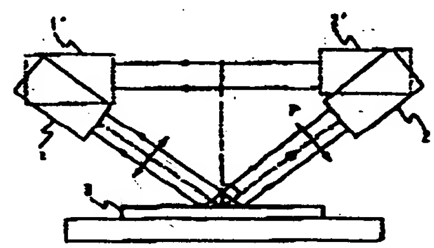

Figure 7

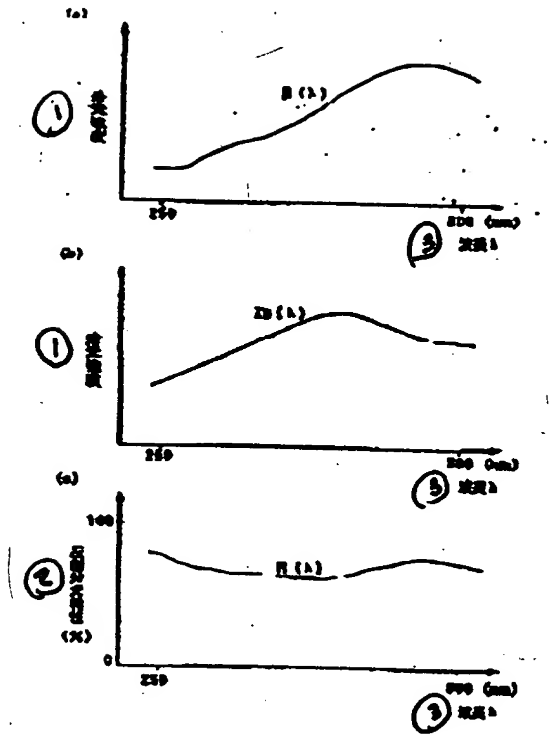

Figure 8

Key: 1 Spectral intensity
2 Reflected spectral characteristics
3 Wavelength λ

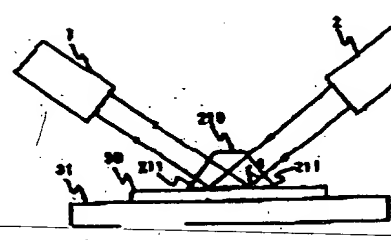

Figure 9

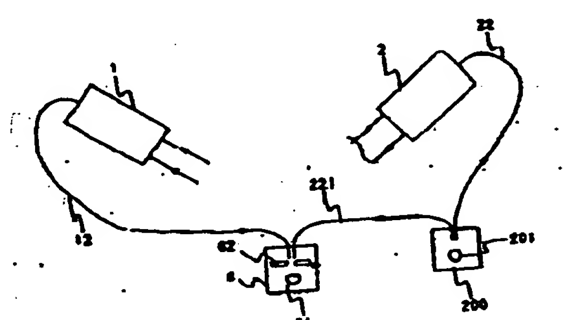

Figure 10

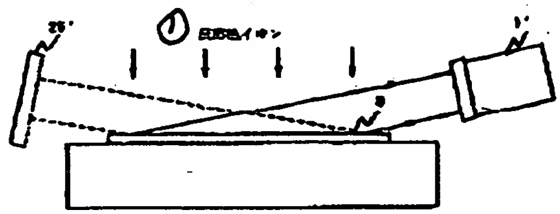

Figure 11

Key: 1 Reactive ions

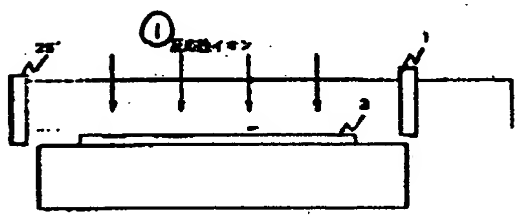

Figure 12

Key: 1 Reactive ions

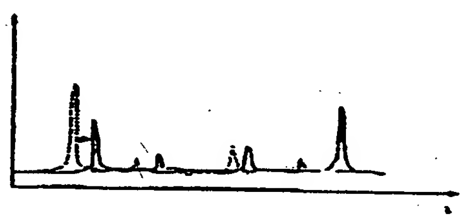

Figure 13